UCRL-85884
PREPRINT

LAMINAR-FLOW DAMPERS FOR STABILIZING THE BEHAVIOR OF PNEUMATIC VIBRATION ISOLATORS

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Submitted for publication to
American Machinist

April 22, 1981

Lawrence Livermore Laboratory

LAMINAR-FLOW DAMPERS FOR STABILIZING THE BEHAVIOR OF PNEUMATIC VIBRATION ISOLATORS*

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ABSTRACT

During the development of the 84-in. diamond turning machine at Lawrence Livermore National Laboratory, we modified a commercially available pneumatic isolator to include a laminar-flow damping system for isolating this precision machine from ground vibration. We developed a configuration of aluminum plates separated by shim stock spacers and substituted this for the usual orifice-flow restrictor for the gas flow in the damping system. This new system gives a leveling response within two seconds and precludes continuous oscillation for the full range of motion amplitudes of interest.

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*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

**Dr. DeBra is a professor of Aeronautics and Astronautics at Stanford University. This work was performed at Lawrence Livermore National Laboratory, where the author was a 1980 summer employee.

Precision machine tools and measuring machines normally require isolation from ground vibration, with a low natural frequency for the isolator/machine system. But such a "soft mount" could allow the machine to tilt along with its changing load if there were not also some self-leveling valves to maintain the height of three support points. The springs that isolate the machine require some damping so that floor motion which occurs at the resonant frequency will not be unduly amplified.

Isolators now commercially available employ a pneumatic spring. Damping is provided by dissipating the energy of a compressed gas through a restrictor into an auxiliary volume. An orifice typically joins the two volumes. However, the damping of an orifice is nonlinear, with the resistance increasing with amplitude of motion. Therefore the orifice size chosen is only optimum for a single amplitude. We found that in a self-leveling system with orifice-damped isolators, some amplitudes of motion have such poor damping that the feedback can render the system unstable.

This problem became evident during the development of the 84-in. diamond turning machine being built at Lawrence Livermore National Laboratory. The machine, as shown in Fig. 1, will require fast leveling. The spindle slide on this machine will weigh 10 tons and move through a distance of 42 in. at speeds up to 15 in./min.

Relatively high gain (gas flow in response to change in height) must be employed. When the isolators for the 84-in. machine were first activated, this high gain resulted in a limit cycle (continuous oscillation) of the 80-ton granite base with an amplitude of nearly 0.040 in. Thus vibration isolation became a secondary question until the limit cycle could be corrected.

LAMINAR-FLOW DAMPING

A control system can be stabilized by a variety of techniques, and in the case of the diamond turning machine, stability was achieved simply by improving the passive damping. We achieved this by replacing orifice damping with a laminar-flow restrictor which provides constant resistance to flow for all amplitudes.

If the flow of a liquid is restricted primarily by viscous shear, the pressure drops and flow will be proportional and therefore the damping produced will be linear. This occurs for laminar flow in which the velocity is low enough to avoid turbulence. A large surface area is needed in order to provide adequate resistance. For the restrictor to operate in laminar flow, a Reynolds number below the transition value of 2000 is required. We found the performance of our devices correlated well with theory when we restricted the flow to values of 500 or less.

Capillary tubes were not suitable since they must be excessively long or too great in number to satisfy the joint requirements of optimum flow resistance and low Reynolds number. Flow between parallel plates has worked well, and the plates can be packaged in a variety of ways. Adequate flow cross section to satisfy the Reynolds number requirement was achieved by stacking plates of aluminum and separating them by shim stock spacers. The spacing chosen is typically in the range of 0.004 to 0.016 in. Figure 2 shows the arrangement of the parallel plates, and Figs. 3 and 4 show the components used on the 84-in. machine. Figure 5 shows the isolator installed under the machine.

Figures 6 and 7 show the comparison between orifice-flow and laminar-flow damping. With orifice damping the system oscillates continuously. Data are shown at two locations to indicate the rocking behavior. The oscillation could be stopped by means of low-gain level-sensing valves, but the penalty was a leveling time in excess of two minutes. By contrast, with the laminar flow dampers and high-gain level-sensing valves installed, the transient response to a man stepping on or off the edge of the machine is less than 2 sec.

With the oscillation problem under control, the isolators perform well. The vibration level on the 80-ton granite base is less than one μin. in either the vertical or the horizontal direction. The floor vibration is 10-15 μin. at 15-22 Hz.

SUMMARY

A few pieces of sheet metal and shim stock bolted together and installed inside the isolator have changed the behavior of the isolator system from disastrous to state-of-the-art. We will issue a full report that gives the detailed design equations in July, 1981.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of the following members of Livermore's Metrology Group who helped bring this project to a successful conclusion: Jim Bryan, Don Carter, Dick Clouser, Jim Hamilton, Richard Warner, Chuck Woods, and Art Caraveo.

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FIGURE CAPTIONS

FIG. 1. The newest diamond turning machine being built at Lawrence Livermore National Laboratory will use laminar-flow damping in the pneumatic isolators (lower left).

FIG. 2. Laminar-flow damping is provided by movement of gas through a set of parallel, separated plates.

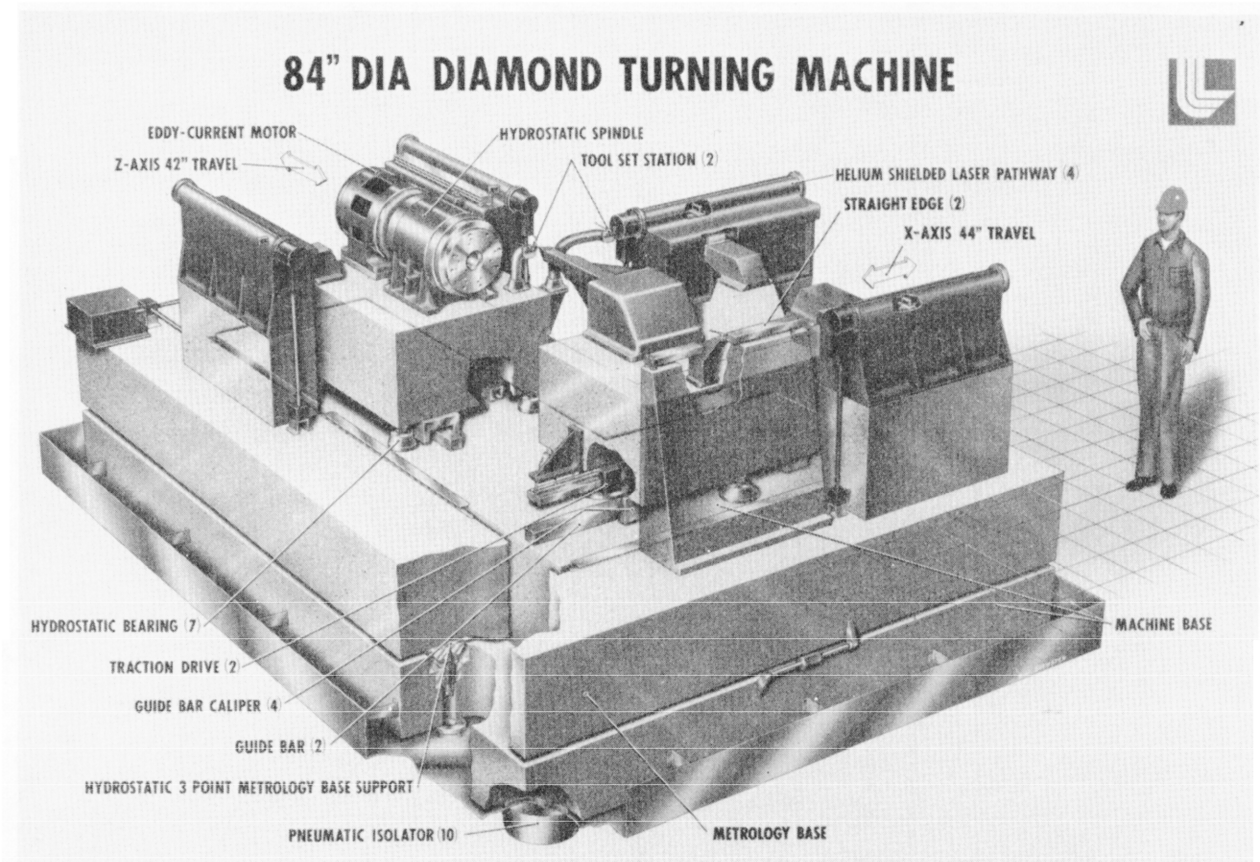
FIG. 3. Aluminum plates and shim stock spacers are assembled into a laminar-flow restrictor.

FIG. 4. The assembled restrictor joins the two chambers of a pneumatic isolator.

FIG. 5. The pneumatic isolator will be one of ten in place under the 84-in. diamond turning machine.

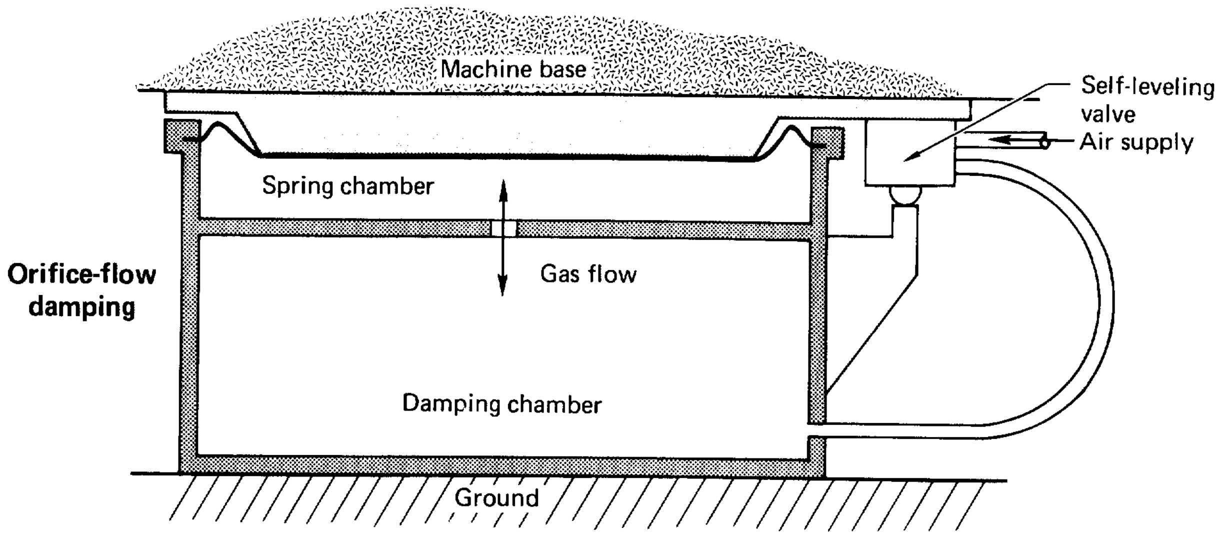
FIG. 6. Limit cycle (continuous oscillation) seen for orifice damping on the 84-in. diamond turning machine.

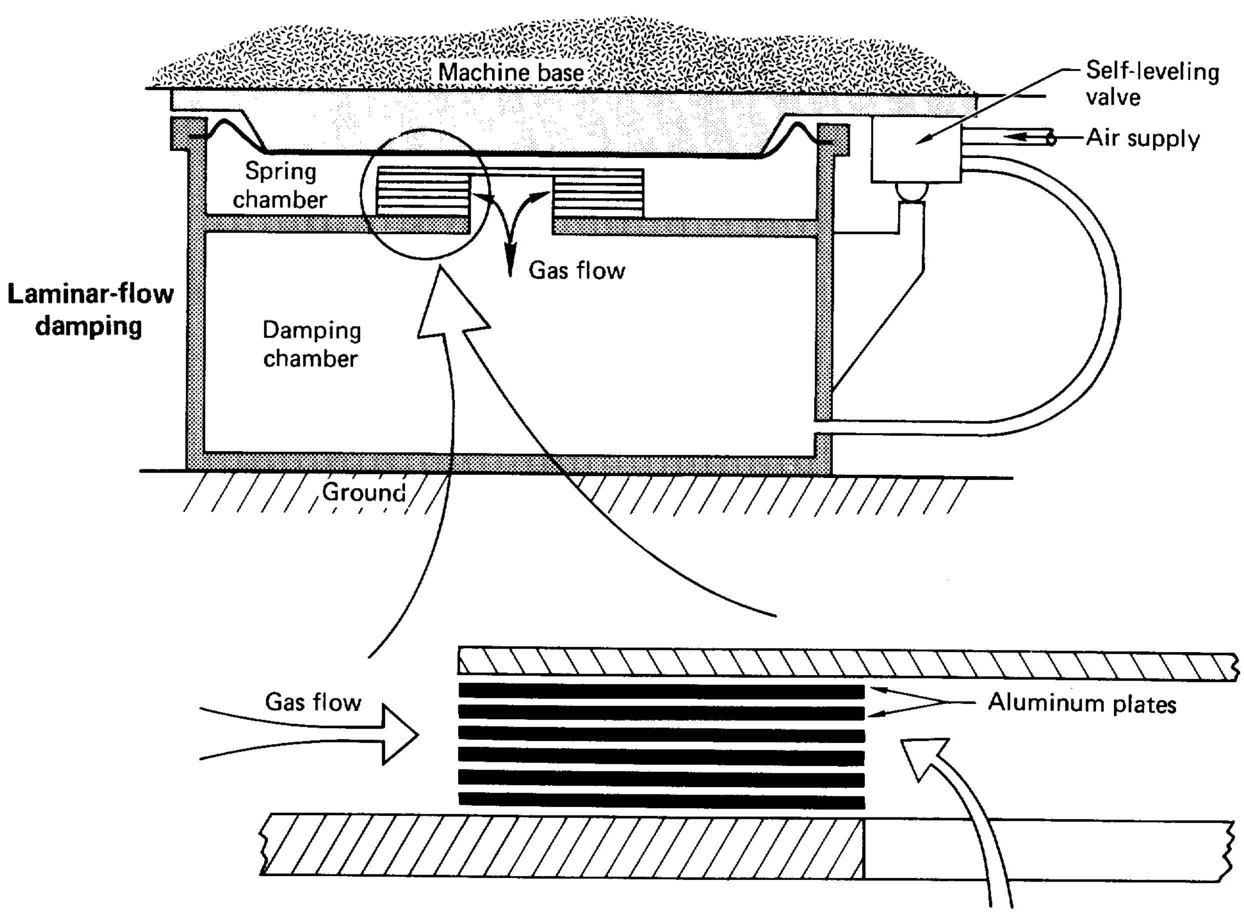
FIG. 7. Laminar-flow isolator and level-sensing valves control displacement within 2 sec after a man steps on or off the machine.



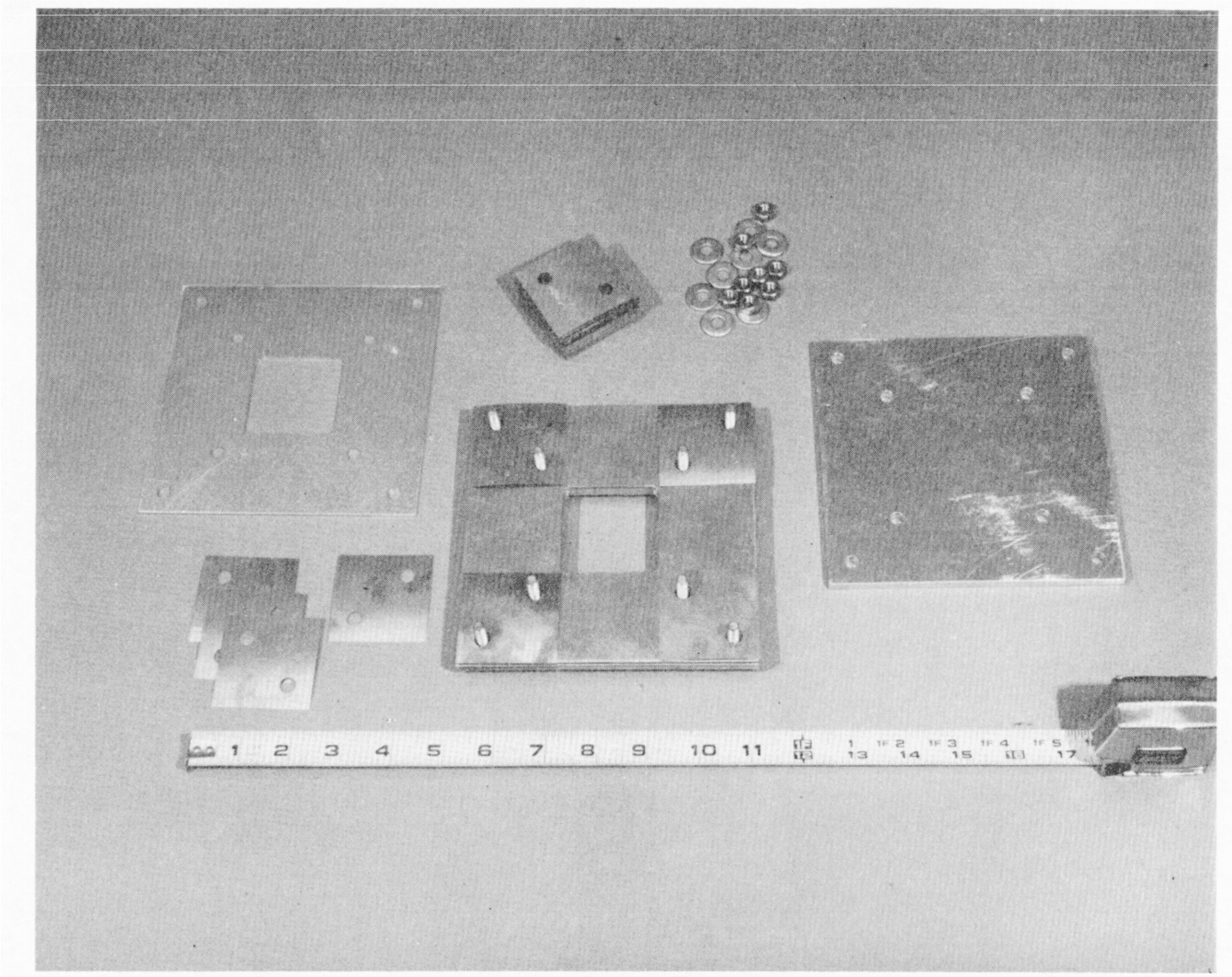
84" DIA DIAMOND TURNING MACHINE
EDDY-CURRENT MOTOR
HYDROSTATIC SPINDLE
Z-AXIS 42" TRAVEL
TOOL SET STATION (2)
HELIUM SHIELDED LASER PATHWAY (4)
STRAIGHT EDGE (2)
X-AXIS 44" TRAVEL
HYDROSTATIC BEARING (7)
MACHINE BASE
TRACTION DRIVE (2)
GUIDE BAR CALIPER (4)
GUIDE BAR (2)
HYDROSTATIC 3 POINT METROLOGY BASE SUPPORT
PNEUMATIC ISOLATOR (10)
METROLOGY BASE

DeBra - Fig. 1.

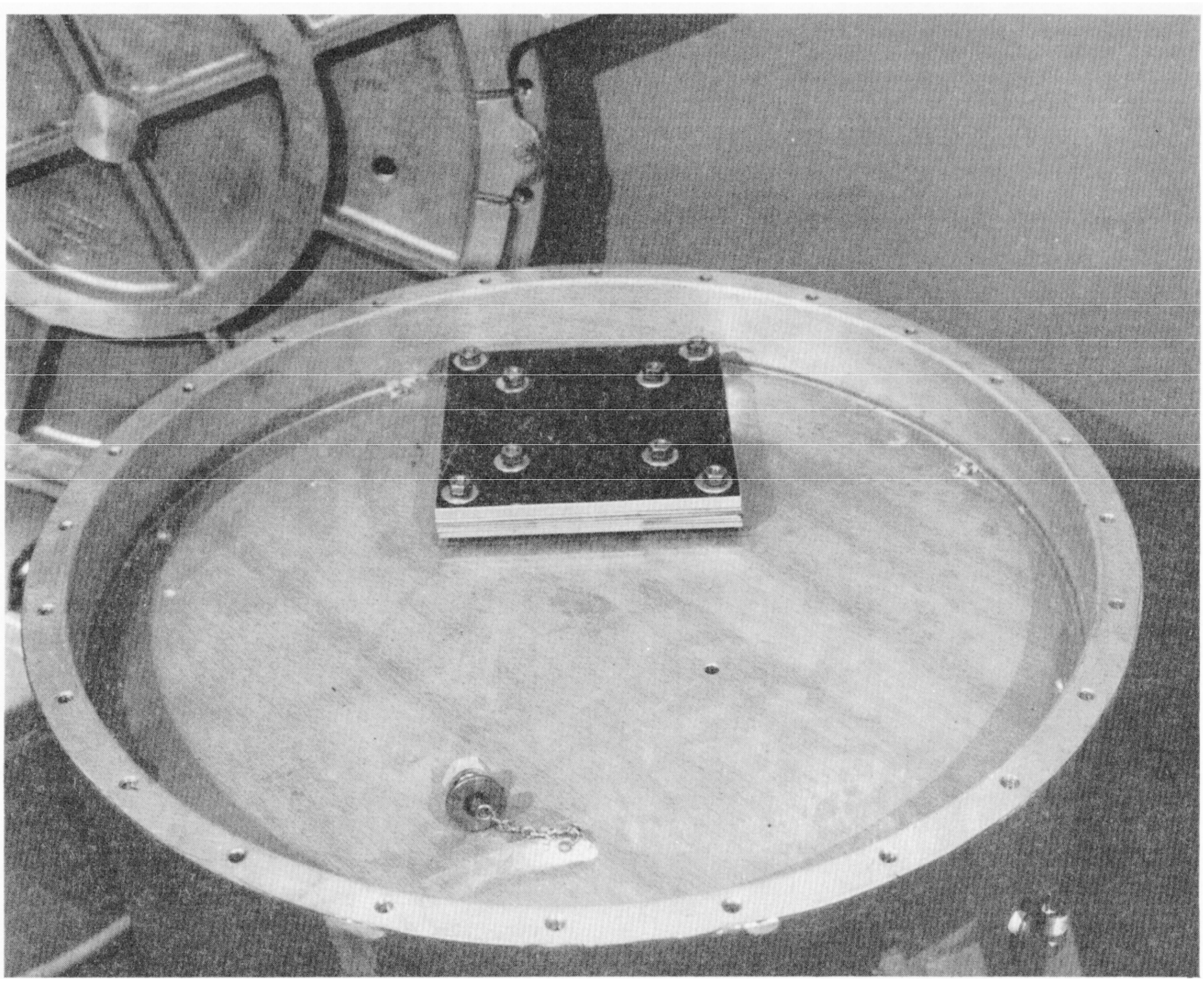

Machine base
Self-leveling valve
Air supply
Spring chamber
Gas flow
Orifice-flow damping
Damping chamber
Ground


Machine base
Self-leveling valve
Air supply
Spring chamber
Gas flow
Laminar-flow damping
Damping chamber
Ground
Gas flow
Aluminum plates

DeBra - Fig. 2.

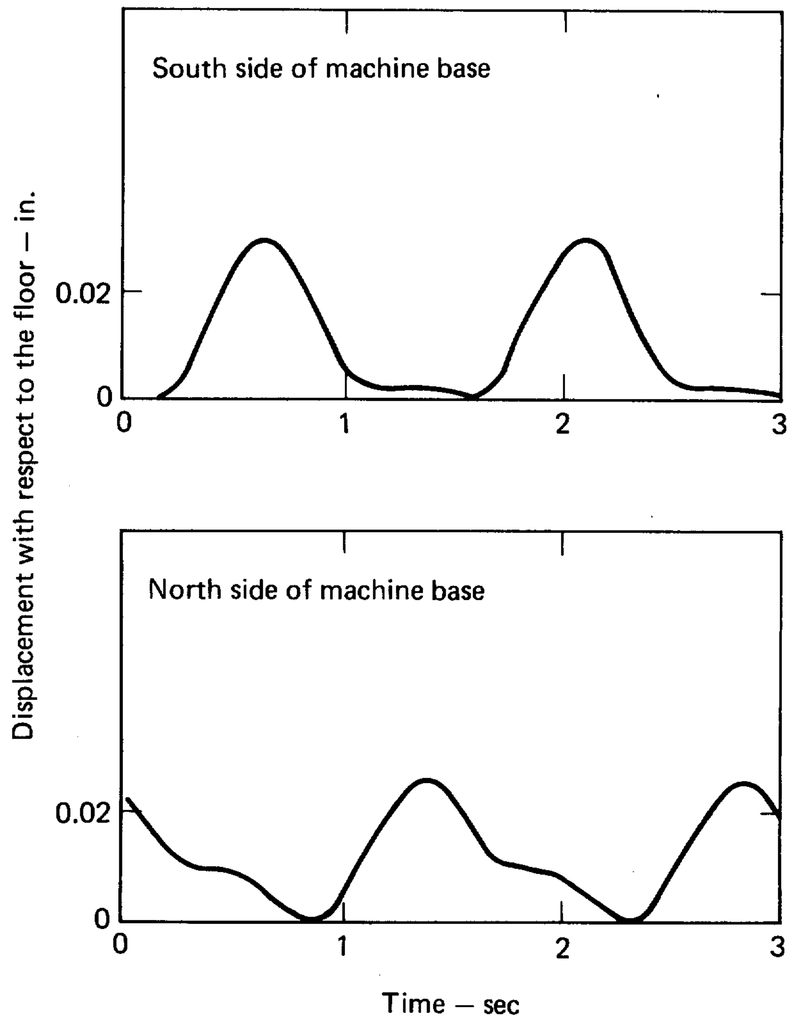


DeBra - Fig. 3.

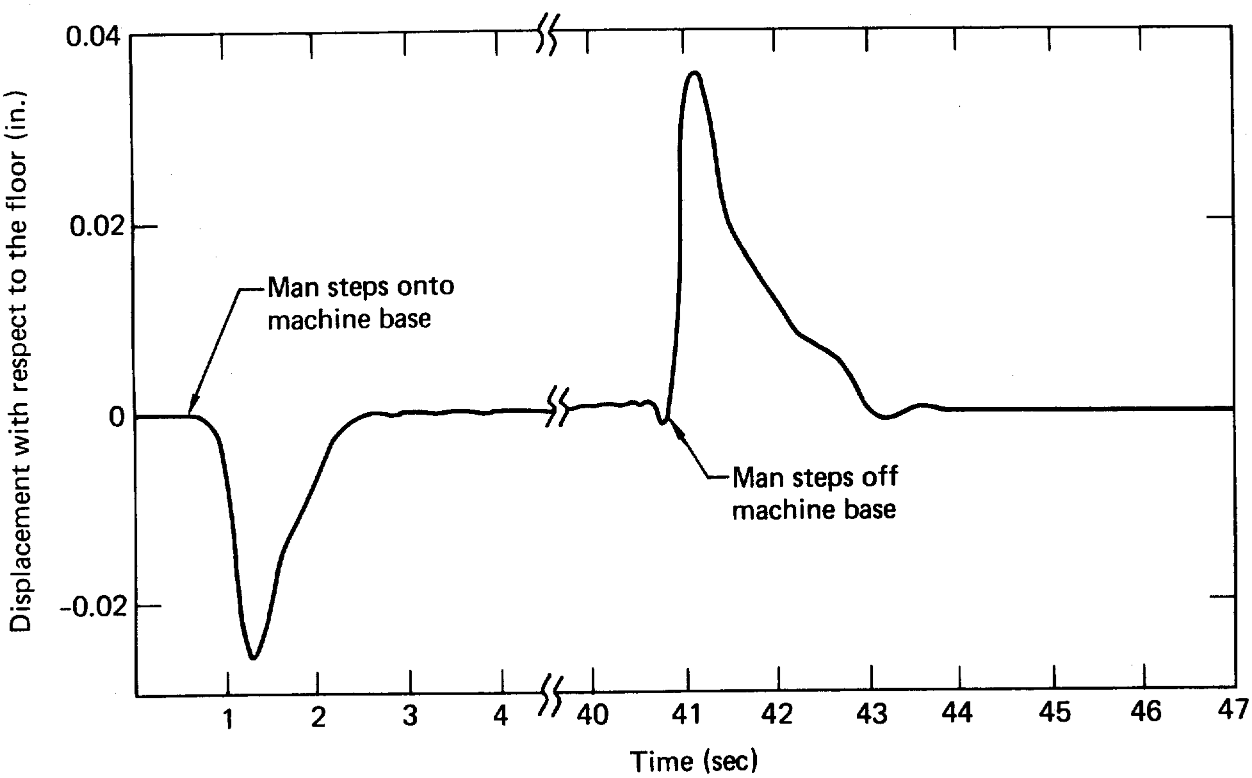


Debra - Fig. 4.

DeBra - Fig. 5.


South side of machine base
North side of machine base
Displacement with respect to the floor — in.
0.02
0
0
1
2
3
Time — sec

DeBra - Fig. 6.



0.04
0.02
0
-0.02
Displacement with respect to the floor (in.)
Man steps onto machine base
Man steps off machine base
1
2
3
4
40
41
42
43
44
45
46
47
Time (sec)

DeBra - Fig. 7.